ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 150 (2016) 1280 – 1286
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Suspension Kinematics Study of the "Formula SAE" Sports Car

S. Chepkasov, G. Markin, A. Akulova*

Ural Federal University, 19 Mira street, Yekaterinburg, 620002, Russia

Abstract

In this article the design of the suspension of a sports car with the class “FORMULA SAE” is considered. A suspension double wishbone is taken as the basis. The main requirements to the characteristics of the suspension of the car of this class are formulated. Calculated suspension scheme is adduced. The mathematical model for determining the position of the suspension depending on the angle of the upper arm has been drawn up. The analysis and the choice of the geometric parameters of the suspension of a sports car with the class «FORMULA SAE» were carried out.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: Racing car; suspension; formula SAE; drivability.

1. Introduction

In our days the most popular automotive events in the world are racing "Formula-1". The cars that are built to participate in these competitions, in addition to traction-speed characteristics have the highest levels of controllability is necessary to ensure maximum speed cornering and safety pilot when driving at extreme speeds.

The need to overcome the curved sections of the track at high speed requires engineers to solve additional tasks associated with performance handling, stability and safety.

When the vehicle turns, there are forces causing the demolition and roll of the car, in order to minimize the negative consequences of which need to be taken into account parameters such as the characteristics of the tire, the kinematics of the suspension and steering and damping characteristics of the suspension. As a consequence, the result on the competition of a car depends on the kinematics of its suspension.

* Corresponding author. Tel.: + 79502027731.
E-mail address: 79502027731@ya.ru

Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.288

When designing the sports car class «FORMULA SAE» authors faced with the need to optimize the geometric parameters of double wishbones, for it was developed a mathematical model of it, performed the analysis and selection of the optimum geometrical characteristics.

2. The kinematics of the suspension of a sports car

Suspension of a sports car should provide the proper kinematics of the wheels of the car and have a minimum weight of the unsprung parts. Almost all of the racing and sports cars equipped with suspension double wishbone in connection with their optimal kinematic parameters. The large size is a disadvantage when installing the suspension of this type of cars intended for daily use, however, when it is used on cars "formula" type it becomes an advantage, since it would change the track width of the car and resist rollover, regardless of the size and structure of the load-bearing framework.

When changing the relative position of double wishbones suspension levers, changes the height of the transverse and longitudinal tilt of the car, so that it is considered that this type of suspension is able to provide the perfect kinematic ratio. On the other hand, the change in distance between the wishbones affects the change of forces acting on the guide devices and hinges. According to the rules [1] has been tasked to select the geometric parameters of double wishbones car (Fig. 1).

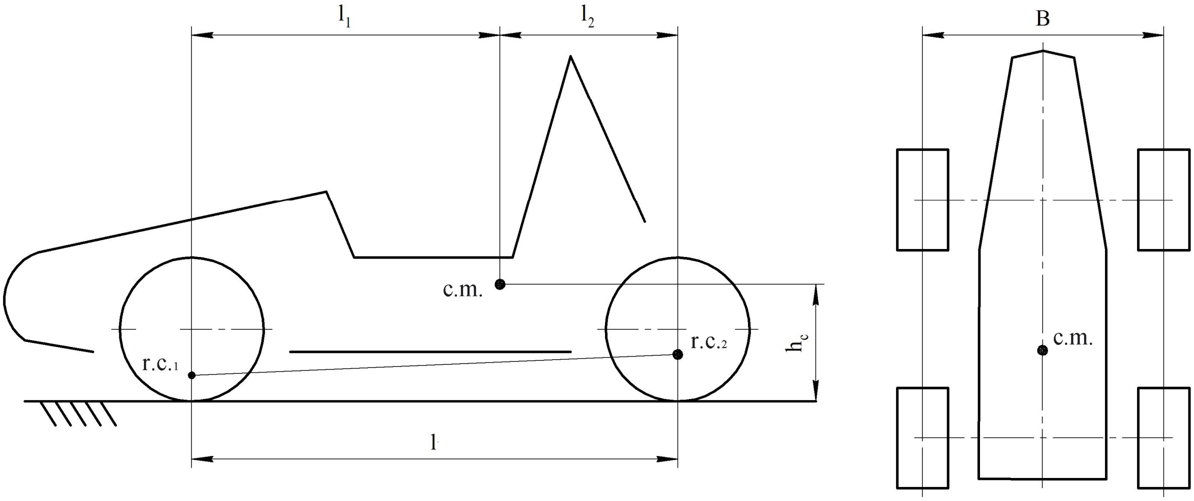

Fig. 1 Diagram of a sports car class «FORMULA SAE»

It is believed that the suspension design issues are among the most interesting for the automotive engineers, because they need creative solutions and a good knowledge of engineering sciences. Great contribution to the study of the issues suspension kinematics introduced Professor J. Reimpel, in his books more fully reflect the various aspects of the design of the chassis of the car, as well as data for various vehicles and formulated key recommendations to the kinematic dependences [2,3]. Among domestic authors distinguish I.N. Uspensky and A.A. Melnikova [4], which sets out the issues of selection and calculation of elastic-damping elements, made recommendations to the choice of the characteristics of the suspension, depending on road conditions. The source [5] provides a general algorithm for selecting parameters of the suspension, formulated the basic load modes. Also, in the preparation of the mathematical model used recommendations and some of the approaches set out in [6].

Requirements for the suspension of a sports car class «FORMULA SAE»:

- Camber angle should vary with the angle the cross- roll the car. So that when the vehicle turns, the suspension provides a constant contact patch. This is necessary to allow the transmission of large lateral forces and more uniform tire wear

- Track change during the course of the suspension should be small and be in the range 5-10 mm to maximize contact with the road wheels
- The length of the pintle should be the maximum possible under the terms of the layout to reduce reactions in joints of levers

3. Mathematical model

In our case, for constructive reasons (for the purpose of rational placing on the frame), the suspension transmits vertical forces on the elastic member through the thrust and rocker arm, itself resilient member is located at the bottom of the frame.

In addition, the following assumptions: suspension components (except springs) are considered to be absolutely rigid. This mathematical model is not taken into account the kinematics of the pusher, in view of complexity of a conclusion of formulas this question is left for future research.

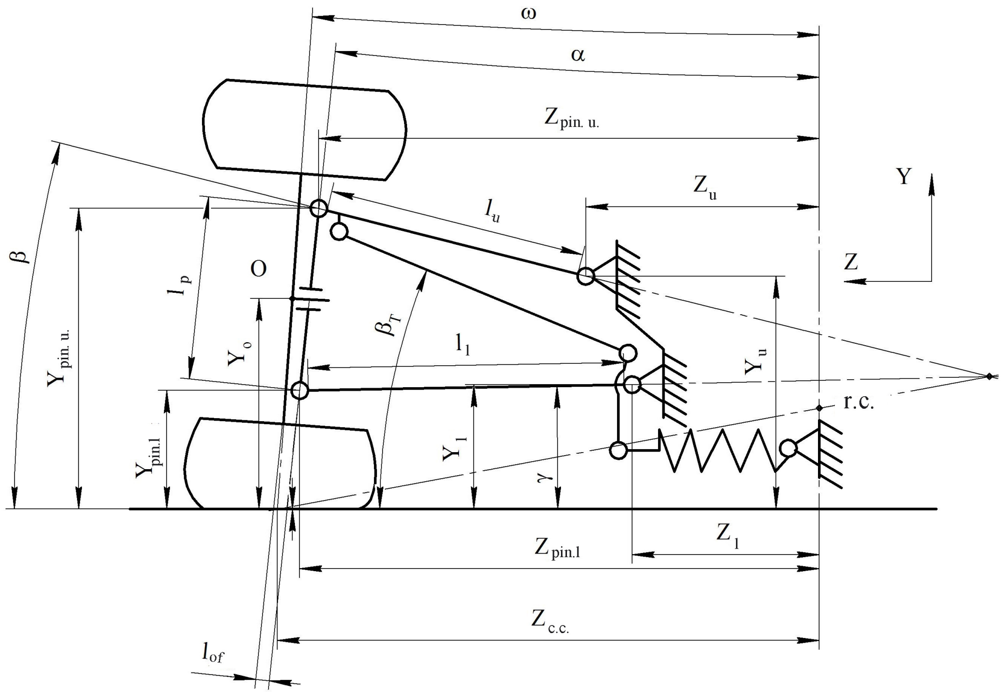

Fig. 2. Estimated scheme of front suspension kinematics.

At the initial stage, taken the original dimensions of the suspension. The initial data are considered coordinates mounting arm to the frame, the lengths of the arms and pintles, the length of disk offset, the camber angle in the initial position and the angle of inclination of the transverse pintle (Fig. 2).

The following symbols are used in Fig. 2: Z_u, y_u – horizontal and vertical coordinates of the upper arm joint respectively; z_l, y_l – horizontal and vertical coordinates of the lower arm joint respectively; $z_{pin.u}$, $y_{pin.u}$– horizontal and vertical coordinates of the hinge pintle of the upper arm, respectively; $z_{pin.l}$, $y_{pin.l}$ – horizontal and vertical coordinates of the hinge pin of the lower arm, respectively; z_o, y_o – horizontal and vertical coordinates of the point O, respectively; $z_{c.c.}$, $y_{c.c.}$– respectively horizontal and vertical coordinate of the center of the contact wheel; l_p – the length of the pintle; l_{of} – the length of the wheel offset; l_u – length of the upper arm; l_l – the length of the lower arm; β – the inclination angle of the upper arm; γ – the angle of inclination of the lower arm; βт – the angle of inclination of the rod; ω – the camber angle; α – angle of inclination of the axis of pintle to the vertical.

For the above calculation scheme was made a mathematical model in Mathcad using the methods of theoretical mechanics and the theory of machines and mechanisms. To check the calculations was built kinematics in Solid Works tied to Microsoft Excel.

The proposed mathematical model has one degree of freedom. As a modifiable parameter selected angle of the upper arm to the horizontal β.

The horizontal coordinate of the upper end of the lever $z_{pin.u}$ calculated by the formula:

$$z_{pin.u} = l_u \cos\beta + z_u \tag{1}$$

The vertical coordinate of the upper end of the lever $y_{pin.u}$ calculated by the formula:

$$y_{pin.u} = l_u \sin\beta + y_u \tag{2}$$

The vertical coordinate at the end of the lower arm ypin.l has rather complicated trigonometric dependence on the parameters, so for the sake of simplicity, additional variables are introduced (Formula 4-10):

$$y_{pin.l} = \frac{-d - \sqrt{D}}{2e} \tag{3}$$

$$d = 2 \cdot \left(\frac{a}{b} \cdot z_{pin.u} - y_{pin.u} - \frac{ac}{b^2} \right) \tag{4}$$

$$D = d^2 - 4eh \tag{5}$$

$$e = \left(\frac{a}{b} \right)^2 + 1 \tag{6}$$

$$a = y_{pin.u} - y_l \tag{7}$$

$$b = z_{pin.u} - z_l \tag{8}$$

$$c = \frac{l_l^2 - l_p^2 - z_l^2 - y_l^2 + z_{pin.u}^2 + y_{pin.u}^2}{2} \tag{9}$$

$$h = -l_p^2 + \left(\frac{c}{b} \right)^2 - 2\frac{c}{b} z_{pin.u} + z^2{}_{pin.u} + y_{pin.u}^2 \tag{10}$$

The horizontal coordinate of the lower end of the lever $z_{pin.l}$ calculated by the formula:

$$z_{pin.l} = \frac{c - a \cdot y_{pin.l}}{b} \tag{11}$$

The angle of inclination of the lower arm γ calculated by the formula:

$$\gamma = \arccos\left(\frac{z_{pin.l} - z_l}{l_l}\right) \tag{12}$$

The angle of inclination of the axis of pintle to the vertical α calculated by the formula:

$$\alpha = \arcsin\left(\frac{z_{pin.l} - z_{pin.u}}{l_l}\right) \tag{13}$$

The camber angle ω calculated by the formula:

$$\omega = \omega_0 + (\alpha - \alpha_0) \tag{14}$$

The vertical coordinate of the point O y_o:

$$y_0 = y_{pin.l} + \frac{l_l}{2} \cdot \cos\alpha \tag{15}$$

The horizontal coordinate of the point O z_o:

$$z_0 = z_{pin.u} - \frac{l_l}{2} \sin\alpha + l_{0f} \cos(\alpha) \tag{16}$$

Vertical coordinate of the center of the contact $y_{c.c}$:

$$y_{c.c.} = y_0 - R_{CT} \cdot \cos\omega \tag{17}$$

The horizontal coordinate of the center of the contact $z_{c.c}$:

$$z_{c.c.} = z_0 - R_{CT} \cdot \sin\omega \tag{18}$$

where $R_{ст}$ – static wheel radius.
Track B:

$$B = 2 \cdot z_{c.c.} \tag{19}$$

Changing tracks ΔB:

$$\Delta B = B - B_0 \tag{20}$$

Consequently, to obtain a mathematical model, it is possible to plot changes in camber and track, depending on the progress of the suspension, setting its geometric parameters.

4. The selection of geometric parameters of the suspension of a sports car class «FORMULA SAE»

The next step is the selection of the geometrical parameters of the suspension of the projected car.
On the basis of the rules and conditions of the layout, the authors established the following limits:

- Suspension travel is 60 mm (30 rebound, compression 30)

- Coordinates the support of the lower arm to the frame defined by the condition of the car layout, so for further calculations are permanent
- The length of the pintle is selected taking into account the requirements set forth and so do not change
- Initial camber -31

Accordingly, the required characteristics can be obtained by changing the mounting points of the upper arm to the frame, a change of the lengths of levers, varying the angle of inclination of the kingpin, tilt levers.

In this paper, as an example, consider the effect of the location of the support of the upper arm and the angle of inclination on the camber angle characteristics and track changes depending on the suspension travel.

Geometrical parameters of suspension have been calculated for the three variants of the position of the upper arm by using formulas (1-20), the results is shown in Table 1 and the graphs (Figure 3).

Table 1. Results of calculation.

Z_B (mm)	Y_B (mm)	β_0 (°)		Suspension travel (mm)						
				-30	-20	-10	0	10	20	30
			B (mm)	1341	1344	1346	1349	1351	1352	1353
270	310	7,2	ΔB (mm)	-8	-5,2	-2,6	0	2	3,2	4
			ω (°)	0,047	0,161	-0,16	-0,52	-0,92	-1,33	-1,73
			B (mm)	1344	1346	1347	1349	1350	1350	1351
268	331	3,8	ΔB (mm)	-5	-3,1	-1,5	0	1	1,6	2
			ω (°)	0	-0,16	-0,34	-0,52	-0,75	-0,97	-1,23
		0	B (mm)	1346	1347	1348	1349	1349	1349	1349
267	354		ΔB (mm)	-3	-2	-1	0	0	0	0
			ω (°)	-0,49	-0,5	-0,52	-0,52	-0,57	-0,63	-0,71

In figure 3 are shown three curves, which illustrate interrelation of the inclination of the upper arm and characteristics of study suspension during suspension travel that allows graphically compare parameters of several options of suspension kinematic. From these graphs it can be concluded that a third option (β=0°) of the installation of the upper arm is more fully satisfy the requirements set forth in this article, since the track remains constant during compression motion and its change during rebound is at a permitted range. The camber angle thus is negative and almost unchanged. It's necessary to note that results, which were received, are valid only for initial conditions described above in this article.

5. Conclusion

In conclusion, the authors would like to note that the resulting mathematical model is universal and allows defining the kinematics of any double wishbones suspension and can be applied not only for sports cars Formula SAE. The next step is the completion of the model and writing a computer program, which would allow plotting the changes of camber and track curves from geometrical parameters, as well as assessing the impact of changes these parameters on the characteristics of the kinematics of the suspension.

Solutions of tasks to optimize the kinematics of the suspension is always quite interesting and original, so the model can be changed and improved for more specific conditions.

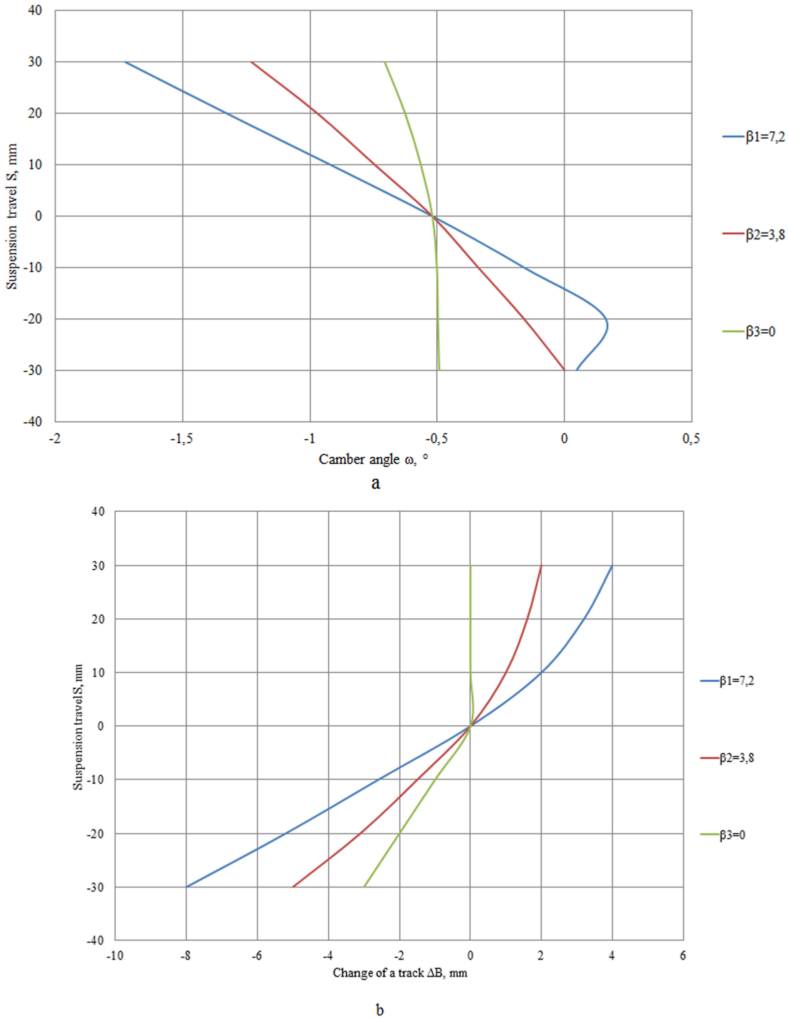

Fig. 3. The influence of the inclination of the upper arm on the horizontal on the kinematics of the suspension; (a) dependence of the camber from the suspension travel; (b) dependence of the track from the suspension travel.

References

[1] Formula SAE, Rules 2016, 2015.
[2] J. Reimpell, Vehicle chassis 1, Vogel-Buchverlag, Wurzburg, 1983.
[3] J. Reimpell, Vehicle chassis: mechanic of elastic suspensions, Vogel-Buchverlag, Wurzburg, 1983.
[4] I.N. Uspensky, A.A. Melnikov, Design of vehicle suspension, Mashinostroenie, Moscow, 1976. (in Russian).
[5] B.A. Afanasiev, B.N Belousov, L.F. Zheglov, Design of four-wheel drive vehicles, Publishing house of the BMSTU, Moscow, 2000. (in Russian).
[6] V.A. Kurdyuk, N.S. Volsky, Method of parameters double wishbones suspension selection from the analysis of the kinematics of the suspension and distribution efforts in the hard points, Vehicles production in Russia: development priorities and training, in: Proceedings of the 77-th International Conference, Moscow. (2012) 96–104. (in Russian).